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Electroweak Results from the Tevatron

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A very brief summary of recent electroweak results from hadron colliders is given. The emphasis is placed on inclusive $W^\pm$ and Z^0 production, the measurement of the mass of the W boson and the measurement of trilinear gauge boson couplings.

1 Intermediate Vector Boson Production and Decay

The measurement of the W and Z production cross sections probes the Standard Model (SM) of electroweak and strong interactions. A persistent uncertainty on any cross section measurement at a $\overline{p}p$ collider, however, is the large uncertainty on the integrated luminosity due to the uncertainty on the effective total $\overline{p}p$ cross section seen by the detectors. This uncertainty cancels almost completely in the ratio of the W and Z production cross sections, a quantity that can be used to extract the width of the W-boson, Γ_W.

W-bosons are identified by requiring an isolated lepton with transverse momentum $p_T > 25$ (20) GeV and $\not{E}_T > 25$ (20) GeV for DØ (CDF). Leptonic decays of Z-bosons are selected by imposing the same lepton quality and kinematic cuts on one lepton, and looser requirements on the second lepton. The vector boson inclusive cross section times decay branching ratio follows from the number of background subtracted candidate events, corrected for efficiency, acceptance and luminosity. The measured cross sections times branching ratio are listed in Table 1, together with the theoretical predictions based on an $\mathcal{O}(\alpha_s^2)$ calculation [1], using the CTEQ2M parton distribution functions (pdf), the calculated value of $B(W \to \ell\nu) = (10.84 \pm 0.02)\%$ [2], and the LEP measurement of $B(Z \to \ell\ell) = (3.366 \pm 0.006)\%$ [3].

	$\sigma_W \cdot B(W \to \ell\nu)$	$\sigma_Z \cdot B(Z \to \ell\ell)$
DØ (e)	$2.38 \pm 0.01 \pm 0.22$	$0.235 \pm 0.003 \pm 0.021$
DØ (μ)	$2.38 \pm 0.03 \pm 0.21$	$0.176 \pm 0.011 \pm 0.022$
CDF (e)	$2.49 \pm 0.02 \pm 0.12$	$0.245 \pm 0.005 \pm 0.018$
CDF (μ)	$2.48 \pm 0.031 \pm 0.16$	$0.233 \pm 0.005 \pm 0.017$
SM	$2.42^{+0.13}_{-0.11}$	$0.226^{+0.011}_{-0.009}$

Table 1. Preliminary results on the measured cross section times branching ratio in nb, and the SM prediction, for W and Z production, based on an integrated luminosity of 89.1 (65.3) and 107.4 (107.4) pb^{-1} for the electron (muon) decay for DØ and CDF, respectively.

The ratio of the W and Z cross section measurements in which the error on the luminosity, common to both the W and Z events, nearly completely cancels, measures the leptonic branching ratio of the W-boson. It can be used, within the framework of the SM, to extract the total width of the W-boson: $R = \frac{\sigma_W \cdot B(W \to \ell\nu)}{\sigma_Z \cdot B(Z \to \ell\ell)} = \frac{\sigma_W}{\sigma_Z} \cdot \frac{\Gamma(W \to \ell\nu)}{\Gamma(Z \to \ell\ell)} \frac{\Gamma(Z)}{\Gamma(W)}$. From the DØ measurement of $R = 10.48 \pm 0.43$ for the combined electron and muon channel, the W leptonic branching ratio is determined to be $B(W \to \ell\nu) = (10.59 \pm 0.44)\%$, using the measured branching ratio for $B(Z \to \ell\ell)$, and the ratio of total cross sections, $\frac{\sigma_W}{\sigma_Z} = 3.33 \pm 0.03$. Combining the published results from UA2, CDF and DØ on the ratio of cross sections, the measured W leptonic branching ratio from $\bar{p}p$ colliders is $B(W \to \ell\nu) = (10.92 \pm 0.32)\%$, to be compared to the current LEP average of $B(W \to \ell\nu) = (10.40 \pm 0.26)\%$ [3]. Using the SM prediction for the partial decay width $\Gamma(W \to \ell\nu) = 225.2 \pm 1.5$ MeV [2], the published results yield a value of $\Gamma_W = 2.062 \pm 0.059$ GeV. With all data combined a final Γ_W uncertainty of 30 MeV is anticipated.

Γ_W can also be measured from the tail of the distribution in transverse mass of W events, defined as $m_T = \sqrt{2 p_T^\ell p_T^\nu (1 - \cos\varphi^{\ell\nu})}$. Here $\varphi^{\ell\nu}$ is the angle between the lepton and neutrino in the transverse plane. The rate of events at high transverse mass is directly proportional to Γ_W, and a likelihood fit to the fraction of events in the region $110 < m_T < 200$ GeV, performed by CDF, gives $\Gamma_W = 2.19^{+0.17}_{-0.16} \pm 0.09$ GeV.

The experiments have also studied the decay $W \to \tau\nu$. The event selections used by DØ and CDF are orthogonal. CDF selects the electronic decays of the W boson and as such measures a ratio of branching ratios. Low E_T electrons are selected with a large impact parameter to distinguish the τ decays from the direct $W \to e\nu$ decays. DØ selects hadronic τ decays and directly measures the production cross section. Narrow jets are selected with low charge multiplicity. As expected, QCD jet production is the dominant background estimated to be of the order of 20% and 11% for CDF and DØ, respectively. The ratio of production cross sections is proportional to the ratio of the square of the leptonic coupling constants, and the measurements yield: $g_\tau/g_e = 1.01 \pm 0.17 \pm 0.09$ (CDF) and $g_\tau/g_e = 1.004 \pm 0.019 \pm 0.029$ (DØ).

The availability of large integrated luminosities opens the possibility to look for rare decays. CDF has searched for the decays $W \to \pi\gamma$ and $W \to D_s\gamma$, with calculated branching ratios of $3.3 \cdot 10^{-9}$ and $1.0 \cdot 10^{-8}$, respectively. Both searches are based on an event sample with a high p_T photon. For the $\pi\gamma$ decay mode a single jet with one associated track is required; for the $D_s\gamma$ mode the decays $D_s^+ \to \varphi\, \pi^+ \to K^+ K^- \pi^+$ and $D_s^+ \to \overline{K^{*0}}\, K^+ \to K^- \pi^+ K^+$ are selected. Backgrounds are estimated using proper "off-mass"

track combinations. In the W-mass window 3 (4) events are observed on an expected background of 5.2 (4) events, resulting in a limit on the ratio $\frac{\Gamma(W\to\pi^{\pm}\gamma)}{\Gamma(W\to e\nu)}$ $\left(\frac{\Gamma(W\to D_s\pm\gamma)}{\Gamma(W\to e\nu)}\right) < 7\cdot10^{-4}$ $(1.1\cdot10^{-2})$ [4].

2 Drell-Yan Production

The measurement of the Z line shape over a large di-lepton invariant mass region through the Drell-Yan process $(q\bar{q} \to (\gamma, Z \to) \ell^+\ell^-)$ allows, in the low invariant mass region, access to the small x region of the parton distribution functions down to $x = 0.006$, where x is the fraction of the proton momentum carried by the parton. The high invariant mass region is populated by high x partons and thus allows for a study of possible substructure of the interacting partons. Substructure of partons is most commonly parametrized in terms of a contact interaction characterized by a phase, η, leading to constructive $(-)$ or destructive $(+)$ interference with the SM Lagrangian, and a compositeness scale, Λ^η, indicative of the energy scale at which substructure would be revealed [5]. The double differential Drell-Yan cross section $d^2\sigma/dM\,dy$ has been measured for leptonic final states for di-lepton invariant masses exceeding 40 (60) GeV/c^2 over the rapidity interval $|\eta| < 1$ (2.4) for CDF (DØ). By fitting the di-lepton invariant mass spectrum to various models for the chirality and interference of the contact interaction, lower limits on the compositeness scale are set. Table 2 lists the 95% CL limits on the compositeness scale factors [6].

|	LL		LR		RL		RR		VV		AA	
Λ_{ij}^+	3.1	3.3	3.3	3.4	3.3	3.3	3.0	3.3	5.0	4.9	4.5	4.7
Λ_{ij}^-	4.3	4.2	3.9	3.6	3.7	3.7	4.2	4.0	6.3	6.1	5.6	5.5

Table 2. One-sided 95% (CDF | DØ) confidence level lower limits on the compositeness scale (in TeV) for different chiralities of the contact interaction and different phases of interference with the SM Lagrangian.

3 W-mass

At hadron colliders the mass of the W boson is measured using the transverse mass, m_T, as defined above. Both the CDF and DØ mass analyses discussed here are based on the Run Ib data, with the CDF analysis based on W decays into muons and the DØ analysis based on electrons. Both experiments anchor their mass measurement to the mass of a known particle. At CDF the momentum scale of the central magnetic tracker is set by scaling the measured J/ψ-mass to the world average value using $J/\psi \to \mu^+\mu^-$ decays. DØ uses a

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combination of $Z \rightarrow ee$, $\pi^0 \rightarrow \gamma\gamma$, and $J/\psi \rightarrow ee$ decays to set the absolute energy scale of the electromagnetic calorimeter.

The W-mass is determined from a maximum likelihood fit of Monte Carlo generated templates in transverse mass to the data distribution. In the Monte Carlo model of W-production the mass dependence of the production cross section is taken to be a relativistic Breit-Wigner resonance, adjusted for parton luminosity effects. The distribution in p_T and rapidity of the W boson is modeled according to the parametrization by Ladinsky and Yuan [7] with a particular choice for pdf. The CDF choice for nominal pdf is the MRS R2- pdf, whereas DØ uses the MRSA pdf. The parameters of the detector model for the simulation are constrained by the data itself. The underlying event is modeled using minimum bias data, mimicking the debris in the event due to spectator parton interactions and the pile-up associated with multiple interactions.
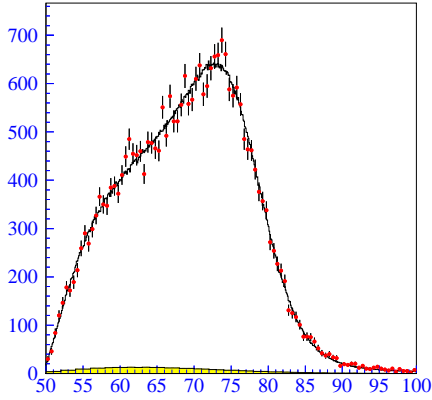
Source	CDF μ	DØ e
Statistical	100	70
Energy/Momentum scale	40	65
Other Systematics	115	65
Calorimeter linearity	—	20
Lepton Angle	—	30
e or μ resolution	25	20
Recoil Model	90	35
W Production Model	55	30
Backgrounds	25	10
Selection Bias	20	5
Fitting procedure	10	—
Total	155	115

The W-mass, as determined from central leptons only, is $M_W^e = 80.440 \pm 0.070(\text{stat.}) \pm 0.090(\text{syst.})$ GeV/c^2 for DØ and $M_W^\mu = 80.430 \pm 0.100(\text{stat.}) \pm 0.120(\text{syst.})$ GeV/c^2 for CDF. The figure shows the transverse mass distribution of DØ and the table lists the systematic errors on the individual measurements [8].

Combining these measurements with previous W mass measurements, with a conservative assumption of a 50 MeV/c^2 correlated uncertainty, gives a world average of $M_W = 80.400 \pm 0.090$ GeV/c^2 from the $\overline{p}p$ collider experiments. Combining with the LEP average of $M_W = 80.37 \pm 0.09$ GeV/c^2 [9] yields an average of $M_W = 80.39 \pm 0.06$ GeV/c^2.

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4 Gauge Boson Pair Production

The non-Abelian $SU(2) \times U(1)$ gauge symmetry of the SM implies that the gauge bosons self-interact. These self-interactions give rise to very subtle interference effects in the SM. In fact, in the SM the couplings are uniquely determined by the gauge symmetry in order to preserve unitarity. Slight deviations of the couplings from their SM values, in the simplest parametrization described by the parameters $\Delta\kappa$ and λ [10], dramatically increase the production cross section and modify differential distributions. Limits on the anomalous couplings $\Delta\kappa$ and λ are thus generally set by either comparing the measured event rate with the expected event rate or by performing a maximum likelihood fit of a measured differential distribution to the expected one for anomalous couplings.

Gauge boson pair production is studied using WZ and WW production in the purely leptonic and in the lepton plus jets final state, and through $W\gamma$ production with the W decaying leptonically. Each process has a different sensitivity to anomalous couplings. Combining all channels, taking into account the correlations between the different analyses, yields stringent limits on the anomalous couplings. The DØ experiment has carried out a combined fit to the three data sets corresponding to the WW, WZ and $W\gamma$ analyses based on the full Run I data and obtains the preliminary results at 68% CL: $\Delta\kappa = -0.08^{+0.34}_{-0.34}$, $\lambda = 0.00^{+0.10}_{-0.10}$. This can be compared to the combined LEP limits of $\Delta\kappa = 0.17^{+0.16}_{-0.16}$, $\lambda = -0.05^{+0.08}_{-0.09}$ [3,9].

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